

Anomalous effective medium approximation breakdown in deeply subwavelength all-dielectric photonic multilayers

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Article Keywords:	dielectric metamaterial, multilayer, effective medium, photonic crystal, photonic crystals, nanostructured device
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Anomalous effective medium approximation breakdown in deeply subwavelength all-dielectric photonic multilayers

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Abstract. We present a comprehensive analysis of the applicability of the effective medium approximation to deeply subwavelength (period $\leq \lambda/50$) all-dielectric multilayer structures. We demonstrate that even though the dispersion relations for such multilayers differ from the effective medium prediction only slightly, there can be regimes when an actual multilayer stack exhibits significantly different properties compared to its homogenized model. In particular, reflection near the critical angle is shown to strongly depend on even very small period variations, as well as on the choice of the multilayer termination. We identify the geometries for which the influence of the subwavelength features is maximized and demonstrate that the difference between the reflectance from the actual multilayer and the effective medium prediction can be as great as 0.98. The results of this analysis can be useful for high-precision multilayers ellipsometry and in sensing applications.

Keywords: dielectric metamaterial, multilayer, effective medium, photonic crystal, nanostructured device.

1. Introduction

Multilayer optics – the study of light propagation in photonic multilayer structures – is the cornerstone subject within the broader field of electrodynamics of inhomogeneous media [1]. On the conceptual level, the multilayer geometry is the simplest possible case of inhomogeneous media: a multilayer structure, being fully homogeneous in two spatial directions and piecewise homogeneous in the third direction, is only one step apart from a truly continuous medium in terms of complexity. On the methodological level, photonic multilayers are subject to several simple and illustrative mathematical theories for their analysis (see, for example, [2] and historical overview in [3]). This concerns both spatially infinite periodic multilayers, which exemplify a very simple variety of one-dimensional photonic crystals [4], and multilayers with a finite number of layers, for which very efficient semi-analytical approaches were developed, based on the transfer matrix [1,2,5] and Airy-type recurrent relations [6,7] formalism. Finally, on the practical level, multilayers easily lend themselves to various planar deposition methods and can, therefore, be fabricated in a reliable and cost-effective manner. For all these reasons, photonic multilayers are one of the most extensively studied optical systems to date, with profound theoretical knowledge and many established applications [8]. As a few characteristic examples, one may mention antireflection coatings, all-dielectric Bragg mirrors and omnidirectional reflectors [9,10], band-pass and multiband-pass filters [2,11,12], devices with tailored

